

FREE-AIR WINDS AT SAN JUAN, P. R.

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More than 500 pilot-balloon observations at San Juan have reached an altitude of 10 kilometers or more up to the present time (October, 1931). Pilot-balloon work was begun there in the summer of 1920, and was at first confined to the summer and autumn months, but from May, 1926 records have been obtained daily throughout the year, except when they were interrupted by inclement weather. In February, 1931, an evening observation was added to the daily program, necessarily limited, however, in altitude owing to fading, or extinguishing, of the small candle light. The number of all observations up to October, 1931, amounts to more than 3,500. On the average between 15 and 20 per cent of the daylight flights attained an altitude of 10 kilometers or higher. Although the visibility seldom is better than six to seven (fair to good), long observations are made possible by the reverse or westerly current above the "trades."

At San Juan the record of long runs is due, in part, to the unremitting interest of Dr. O. L. Fassig under whose direction this work was started in 1920.

The following summation of the seasonal averages at the several levels is of interest particularly as it relates to the winds in the upper layers of the troposphere and the lower stratosphere. With this in mind, the averages have been based on the flights which attained the 10-kilometer level or higher. A paper by Doctor Fassig in the MONTHLY WEATHER REVIEW, vol. 52, January, 1924, covers some of the more interesting records made up to that time. The following data include also such of those earlier observations as pertain to the extreme altitudes. Owing to the greater number of years in which observations were made in the summer and autumn periods, larger proportions of the data refer to those seasons than to the others. It is believed, however, that there are sufficiently numerous observations to fairly represent each of the four seasons. This grouping and also that by levels are given in Table 1.¹

TABLE 1.—Number of observations by seasons and different levels, San Juan, P. R.

Observations:	
Spring.....	62
Summer.....	167
Autumn.....	234
Winter.....	44
Annual.....	507
Surface to—	
10 kilometers.....	507
11 kilometers.....	378
12 kilometers.....	271
13 kilometers.....	172
14 kilometers.....	90
15 kilometers.....	54
16 kilometers.....	25
17 kilometers.....	17
18 kilometers.....	11
19 kilometers.....	9
20 kilometers.....	8
21 kilometers.....	6
22 kilometers.....	4
23 kilometers.....	2
24 kilometers.....	2
25-33 kilometers.....	1

¹ The results for heights above 15 kilometers must be accepted with the reservation that they are based on single theodolite observations and therefore on an assumed ascensional rate for which sufficient confirmation data by two theodolites have not yet been obtained.

Throughout the year the surface winds frequently are from some easterly point. An east component occurred in 64 per cent of all such winds under consideration. However, the chief surface component, found in 85 per cent of the cases, is southerly, particularly in the early morning hours. This off-shore wind shifts to more easterly by 9 or 10 a. m. Table 2 gives the percentage of annual and seasonal frequencies of wind directions at the surface and in the upper levels to 10 kilometers, while Figure 1 shows the summer and winter directions percentages at the surface and at the 2, 6, and 10 kilometer levels. It will be noted that the prevailing component is easterly up to 4 kilometers in all seasons and to 6 kilometers in the summer period, and westerly at the 8 and 10 kilometer levels.

TABLE 2.—Percentage frequency of winds observed from various directions at San Juan, P. R.

SPRING														
Altitude (meters)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	NNW
Surface.....	0	0	0	10	15	15	25	20	11	2	2	0	0	0
1,000.....	0	2	0	6	36	38	18	0	0	0	0	0	0	0
2,000.....	0	3	0	20	28	25	12	5	3	1	0	1	1	0
4,000.....	5	7	7	12	25	7	3	2	6	1	8	3	3	5
6,000.....	12	12	3	12	3	0	3	0	0	2	8	14	8	14
8,000.....	2	6	5	0	2	0	0	0	0	3	20	8	28	16
10,000.....	3	1	0	0	0	0	0	0	0	1	1	3	35	13
SUMMER														
Surface.....	0	0	0	6	16	18	26	15	12	3	2	1	1	0
1,000.....	1	0	0	2	40	39	14	2	1	1	0	0	0	0
2,000.....	0	1	1	11	28	36	15	3	2	1	0	1	0	0
4,000.....	2	5	10	15	17	16	14	7	4	3	3	2	0	1
6,000.....	6	5	10	13	11	9	10	4	4	3	5	5	4	3
8,000.....	7	3	5	5	6	3	4	2	7	5	5	12	11	7
10,000.....	6	6	9	5	3	3	2	3	3	4	7	12	16	5
AUTUMN														
Surface.....	0	0	1	1	2	5	16	26	30	15	3	1	0	0
1,000.....	0	1	4	11	22	30	16	5	5	2	0	1	1	1
2,000.....	2	4	4	9	23	20	14	7	3	3	2	2	2	2
4,000.....	5	4	10	11	9	11	5	6	9	6	7	4	6	1
6,000.....	6	8	7	6	5	6	5	5	8	9	6	7	6	7
8,000.....	10	8	7	5	4	3	3	3	4	6	9	8	11	8
10,000.....	9	8	5	3	3	3	3	2	2	4	5	6	12	13
WINTER														
Surface.....	0	0	0	2	0	7	16	27	30	11	7	0	0	0
1,000.....	2	0	5	15	48	18	5	5	0	0	0	2	0	0
2,000.....	2	7	2	20	25	23	9	0	0	0	0	5	2	5
4,000.....	0	7	4	16	16	14	2	2	0	7	5	2	11	0
6,000.....	2	11	11	0	5	11	5	2	0	7	2	11	16	5
8,000.....	2	7	7	0	2	0	6	0	0	5	9	14	25	5
10,000.....	2	0	0	4	0	0	0	0	0	5	0	14	27	23
ANNUAL														
Surface.....	0	0	0	4	8	11	20	22	22	9	3	1	0	0
1,000.....	1	1	2	8	32	33	15	3	3	2	0	1	1	1
2,000.....	1	3	2	12	26	26	14	5	2	2	1	2	1	1
4,000.....	4	5	9	13	13	13	7	6	6	5	5	3	4	1
6,000.....	6	6	8	9	7	7	6	4	5	6	6	8	7	6
8,000.....	7	6	6	4	2	2	5	2	4	5	7	11	11	8
10,000.....	7	5	5	3	2	2	2	2	2	4	5	9	17	16

Table 3 shows the frequencies of different wind components at and above the 10-kilometer level. North and west components persist up to 15 kilometers, then south

and west or south and east to 16 or 17 kilometers, and finally, north and east components at the 18 to 22 kilometer levels. Two flights were followed to a height of 24 kilometers and one to 33 kilometers. The latter is discussed in detail in the MONTHLY WEATHER REVIEW, January, 1924, referred to above.

TABLE 3.—Percentage frequency of wind components in levels at and above 10 kilometers

Direction between—	Kilometers												
	10	11	12	13	14	15	16	17	18	19	20	21	22
SSW. and NNW. (W.).....	70	69	65	70	60	69	52	29	27	0	25	33	22
SSE. and NNE. (E.).....	21	22	24	20	31	24	36	41	73	78	62	67	75
ESE. and WSW. (S.).....	26	22	27	28	34	35	56	53	36	11	38	33	0
WNW. and ENE. (N.).....	55	63	56	53	54	56	28	29	45	44	50	50	75
No. of observations.....	507	398	271	172	91	54	25	17	11	9	8	6	4

NOTE.—2 observations to 24 kilometers with ENE. to E. and ESE. to WNW. at 23 and 24 kilometers respectively; 1 observation to 33 kilometers with change in direction from 25 kilometers to 33 kilometers, in the following shift—W. to SE. to S. to WNW. to SW. at 33 kilometers, velocity 3 to 15 meters per second.

Owing to the small number of observations at the higher levels their averages are somewhat unreliable. There seems, however, to be a well-defined north by westerly current from the 7-kilometer level to the fifteenth, and a fairly continuous east component in the winds above the 17-kilometer level.

TABLE 4.—Mean free-air winds at San Juan, P. R.

[Velocity in meters per second]

Altitude (meters)	Spring		Summer		Autumn		Winter		Annual	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
Surface	S-48-E	3.0	S-47-E	2.3	S-15-E	1.9	S-14-E	2.2	S-29-E	2.2
500	S-77-E	8.7	S-75-E	8.2	S-70-E	5.9	S-87-E	7.6	S-74-E	7.1
1,000	S-75-E	9.2	S-72-E	8.7	S-70-E	5.9	S-82-E	7.9	S-72-E	7.4
2,000	S-79-E	6.1	S-74-E	7.4	S-76-E	5.0	N-87-E	6.0	S-77-E	6.0
3,000	N-77-E	5.5	S-73-E	6.3	S-68-E	4.4	N-77-E	5.1	S-76-E	5.2
4,000	N-82-E	4.9	S-81-E	5.3	S-76-E	4.1	N-74-E	5.0	S-81-E	4.7
5,000	N-40-W	4.9	E	5.1	S-49-E	4.8	N-14-E	5.8	S-53-E	5.2
6,000	N-43-W	6.0	N-85-E	4.8	S-15-W	4.8	N-40-W	7.2	N-53-E	5.2
7,000	N-53-W	8.5	N-12-W	5.2	N-73-W	5.5	N-55-W	9.0	N-47-W	6.0
8,000	N-59-W	10.9	N-58-W	6.1	N-56-W	6.6	N-77-W	9.4	N-60-W	7.2
9,000	N-66-W	14.2	N-67-W	6.3	N-51-W	7.3	N-74-W	13.1	N-62-W	8.3
10,000	N-70-W	18.0	N-69-W	8.1	N-43-W	9.5	N-73-W	17.0	N-60-W	10.7
11,000	N-69-W	18.4	N-65-W	9.2	N-50-W	10.7	N-74-W	21.9	N-60-W	11.5
12,000	N-71-W	18.1	N-67-W	9.5	N-44-W	11.4	N-73-W	21.6	N-58-W	12.0
13,000	N-72-W	19.4	N-69-W	9.8	N-61-W	12.2	N-68-W	20.3	N-65-W	12.5
14,000	N-62-W	21.0	N-87-W	10.5	N-50-W	11.5	N-20-W	22.0	N-65-W	13.0
15,000	N-68-W	20.8	N-49-W	13.0	N-68-W	12.8	N-19-W	22.0	N-59-W	14.9

Table 4 gives the mean free-air winds and Table 5 the free-air resultant winds, by seasons and for the year from the surface to the 15-kilometer level.² Figure 2 shows the mean free-air wind directions and velocities. Here we note that in the spring the wind is easterly below the 4-kilometer level and westerly above; in the summer, easterly up to the 6-kilometer level but westerly at and beyond 7 kilometers; in autumn and winter, easterly up to 5 kilometers and westerly at and above 6 kilometers. In the free-air resultant winds no marked difference in direction occurs, compared with that of the average winds, but there is some reduction in velocity which is particularly evident in the summer and autumn months when the persistence of easterly winds to higher levels tends to lower the values of the resultant westerly speeds.

² In obtaining "mean" or "average" winds the directions and velocities are considered independently, whereas, "resultant" winds are determined by first resolving each observation into its north and west components and then adding these vectorially.

TABLE 5.—Free-air resultant winds at San Juan, P. R.

[Velocity in meters per second]

Altitude (meters)	Spring		Summer		Autumn		Winter		Annual	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
Surface	S-73-E	2.3	S-59-E	1.9	S-19-E	1.5	S-22-E	1.6	S-42-E	1.8
500	S-79-E	8.3	S-73-E	7.7	S-73-E	5.0	S-88-E	7.0	S-76-E	6.5
1,000	S-75-E	8.2	S-77-E	8.0	S-72-E	4.9	S-78-E	7.3	S-77-E	6.7
2,000	S-82-E	5.1	S-75-E	6.7	S-75-E	3.5	N-88-E	4.5	S-77-E	4.8
3,000	N-89-E	3.5	S-82-E	3.4	S-73-E	2.0	N-73-E	2.8	S-82-E	2.7
4,000	N-85-E	2.2	S-80-E	3.5	S-71-E	1.4	N-67-E	1.7	S-82-E	2.1
5,000	N-5-W	0.7	N-88-E	2.7	S-54-E	0.6	N-88-E	0.2	S-88-E	1.2
6,000	N-43-W	2.4	N-84-E	1.4	N-39-W	0.4	N-14-W	0.8	N-31-E	0.6
7,000	N-55-W	5.0	N-34-W	0.6	N-34-W	0.9	N-70-W	3.4	N-51-W	1.2
8,000	N-64-W	8.8	N-52-W	2.0	N-50-W	1.6	N-81-W	5.0	N-61-W	2.7
9,000	N-66-W	11.5	N-69-W	2.2	N-46-W	2.9	N-77-W	9.0	N-62-W	4.0
10,000	N-74-W	16.7	N-75-W	3.2	N-39-W	4.5	N-76-W	14.6	N-64-W	6.0
11,000	N-72-W	16.8	N-63-W	4.0	N-50-W	5.4	N-76-W	19.7	N-76-W	6.0
12,000	N-72-W	16.9	N-64-W	3.8	N-47-W	5.9	N-80-W	20.0	N-61-W	6.7
13,000	N-72-W	19.4	N-80-W	4.4	N-50-W	6.4	N-75-W	16.8	N-68-W	7.1
14,000	N-67-W	16.4	N-86-W	4.1	N-55-W	3.6	N-17-W	18.7	N-65-W	6.8
15,000	N-68-W	20.8	N-61-W	8.1	N-60-W	4.4	N-17-W	16.9	N-52-W	7.8

The proportion of clockwise to counter-clockwise east-to-west shifts, which generally occur near the 6-kilometer level, was tabulated for each season. An average of 65 per cent turn counter-clockwise in the winter and spring months, and 54 per cent during summer. In the autumn, when the southeast trades are deeper, 52 per cent of the shifts are clockwise.

TABLE 6.—Free-air resultant winds at San Juan, P. R. (1926-1931)

[Velocities in meters per second]

Altitude (meters)	Spring		Summer		Autumn		Winter		Annual		Observations
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	
Surface	S-83-E	2.5	S-82-E	2.9	S-65-E	1.6	N-86-E	2.7	S-82-E	2.5	1,725
500	S-81-E	7.9	S-83-E	8.6	S-86-E	7.6	N-82-E	7.6	S-87-E	7.6	1,725
1,000	S-79-E	7.9	S-78-E	9.6	S-83-E	6.7	N-84-E	8.0	S-84-E	8.0	1,709
2,000	S-81-E	5.0	S-78-E	8.6	S-83-E	5.3	N-82-E	6.3	S-84-E	6.1	1,496
4,000	S-7-W	0.2	S-78-E	4.6	S-81-E	2.5	N-66-E	2.6	S-85-E	2.2	985
6,000	N-78-W	4.8	S-76-E	1.7	N-50-E	1.0	N-54-W	2.9	N-59-W	1.3	668
8,000	N-72-W	8.9	N-65-W	1.1	N-15-W	1.8	N-74-W	8.9	N-66-W	4.2	458
10,000	N-65-W	16.8	N-71-W	3.0	N-25-W	5.2	N-71-W	16.4	N-61-W	6.3	305

Table 6 shows the resultant winds based on all the observations obtained from 1926 to October, 1931. From the surface to 1,000 meters the number of observations in this group is approximately 1,700. The number decreases as the higher levels are approached until at 6 kilometers it is only slightly in excess of the number used as the basis for Tables 4 and 5. Differences in the two sets of averages appear inconsiderable and indicate, in the main, only a difference in the wind-shift level. Thus, in Table 5 the first westerly component (annual) appears at the 7-kilometer level, while in Table 6, with a somewhat greater number of observations as a basis, the north-by-west winds occur first at the height of 6 kilometers. Presumably, therefore, the average reversal level for the year over a long period is somewhat under 6 kilometers.

In October, 1931, conditions were favorable for extended upper-air observations as is generally true of the autumn period. An observation of particular interest occurred on October 21, 1931, the horizontal projection of which appears as Figure 3. Conditions on the morning of the flight were normal at the station, barometer 29.97 inches (sea level), temperature 76° F., surface wind from the southeast, velocity 4 m.p.s., and visibility 7

(good). To the north a cyclonic disturbance of moderate development, which had moved up from the western Caribbean between the seventeenth and twentieth, lowest pressure 29.7 inches, was central on the morning

3] are N. by E.). The pressure in all three instances was generally high throughout the north and middle Atlantic.

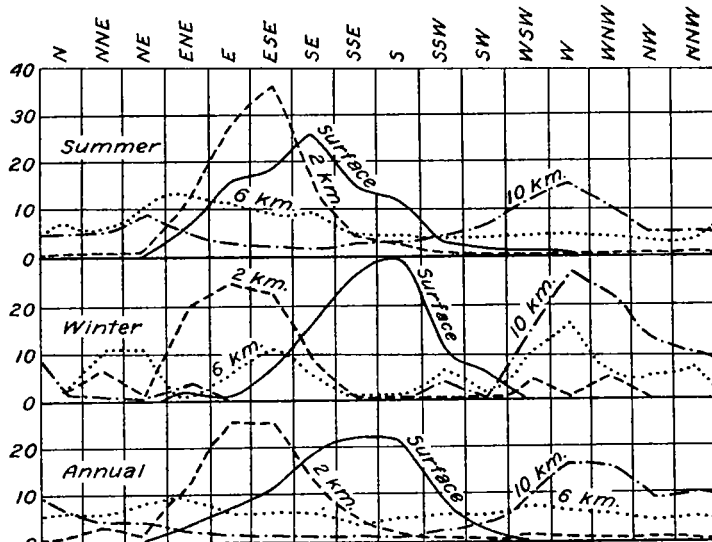


FIGURE 1.—Percentage frequency of winds from different directions at the surface 2, 6, and 10 kilometers, at San Juan, P. R.

of the 21st at latitude 29° N. and longitude 68° W. The balloon was observed to the altitude of 17.9 kilometers. The winds were southeast to south to southwest and west up to 7.6 kilometers; at 8 kilometers they shifted to north and northeast, and were light to 9.5 kilometers, then northwest, west, and southwest to 10.5 kilometers. Between 10.7 and 16.5 kilometers there was an east component—ESE. to SE.—shifting to SSW. at 16.6 kilometers, with a marked increase in velocity to 29.5 m.p.s. from SSW. at the maximum altitude of 17.9 kilometers. The southerly component presumably was due to the barometric depression to the north of the station. Three

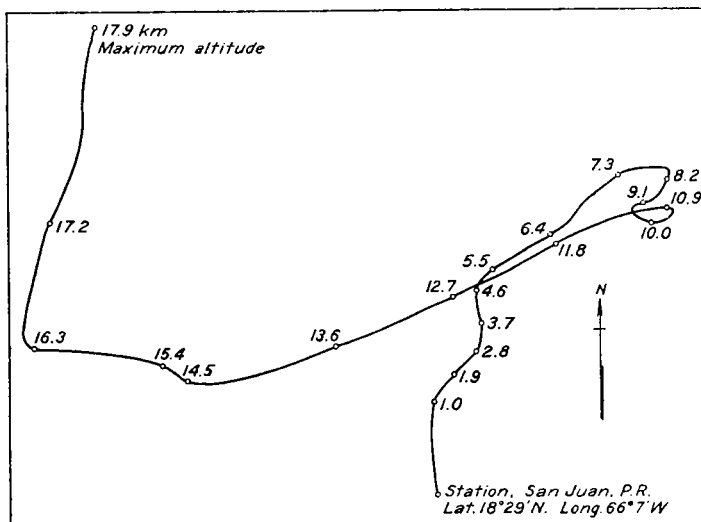


FIGURE 3.—Horizontal trajectory of pilot-balloon flight of October 21, 1931, cyclonic disturbance to the north, central in latitude 29° N., longitude 68° W. (elevation in kilometers and tenths indicated along the curve)

other flights during this same month were observed to elevations of 15 to 17 kilometers, and each showed a northerly component of the wind at its maximum altitude. (The average winds at 17 to 18 kilometers [Table

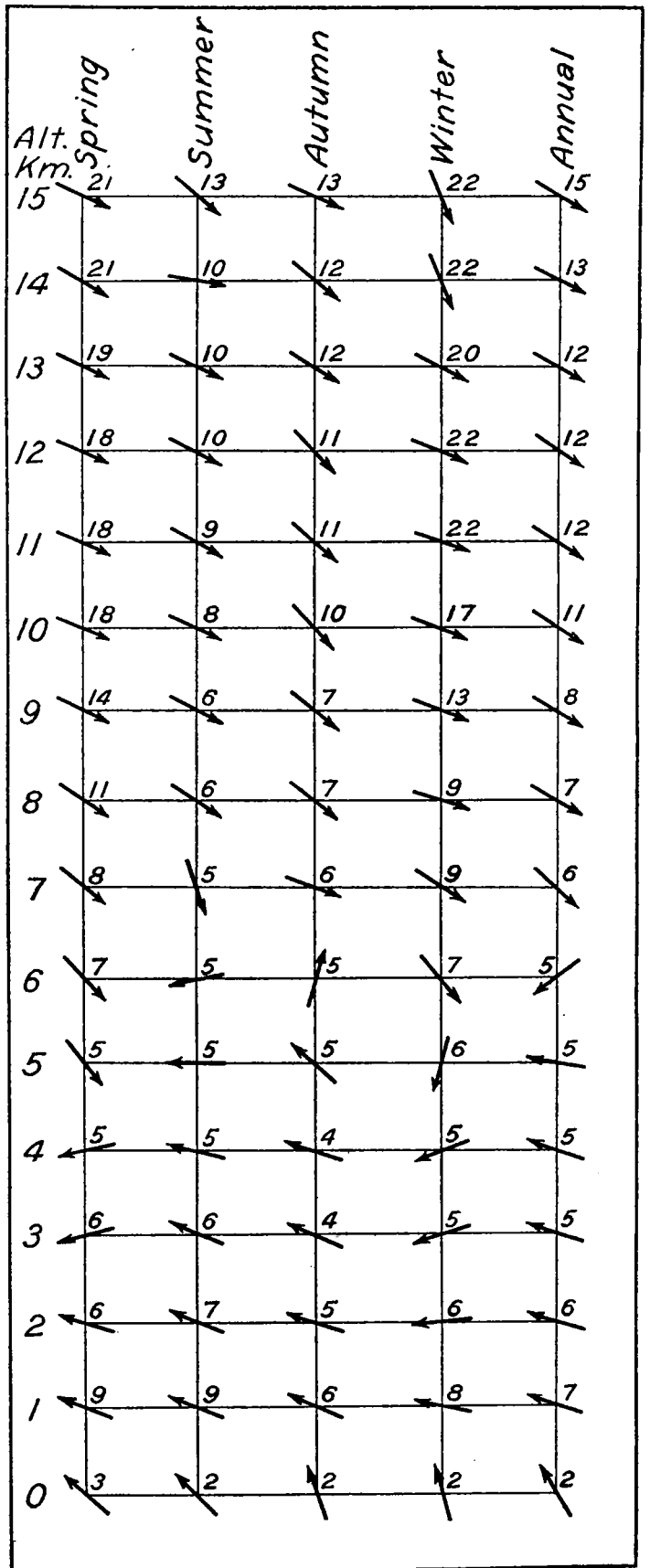


FIGURE 2.—Average free-air winds, direction, and velocities (m.p.s.) at San Juan, P. R.